Electronic Version

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Claims

[c1] What is claimed is:

1.An apparatus for generating electrical power in a tubular housing disposed in a borehole wherein drilling fluid flows through the tubular housing, the apparatus comprising:

a first stator adapted for being secured within the tubular housing against rotation relative to the tubular housing, the first stator having an array of conductive windings therein;

a tubular first rotor rotatably carried about the first stator, the first rotor having an array of magnets therein; and

an impeller peripherally affixed to the first rotor;

whereby drilling fluid flowing through the tubular housing when the apparatus is disposed therein engages the impeller and induces rotation of the first rotor about the first stator to generate electrical power.

[c2] 2.The apparatus of claim 1, wherein the first rotor and first stator are sized and shaped so as to define at least one entrance and at least one exit for conducting drilling fluid between the first rotor and first stator, and further

comprising a plurality of bearings for supporting movement of the first rotor relative to the first stator, the bearings being lubricated by the drilling fluid.

[c3] 3.The apparatus of claim 2, wherein the first rotor and first stator are sized and shaped so as to define a fluid-conducting annular gap between the first rotor and the first stator, whereby the flowing of drilling fluid through the tubular housing when the apparatus is disposed therein also induces conductance of the drilling fluid through the gap to remove heat from the first stator.

[c4] 4.The apparatus of claim 3, wherein the gap has a diameter that generally increases in the downstream direction, so as to promote movement of particles in the drilling fluid through the gap.

[c5] 5.The apparatus of claim 3, wherein the gap has a thickness that generally increases in the downstream direction, so as to promote movement of particles in the drilling fluid through the gap.

[c6] 6.The apparatus of claim 2, wherein the first rotor is equipped with a generally radial channel therethrough intermediate the one entrance and one exit so as to facilitate the removal of particles in the drilling fluid disposed between the first rotor and the first stator.

[c7] 7.The apparatus of claim 2, wherein the impeller defines a turbine rotor, and further comprising a turbine stator having

a tubular body attached coaxially to an upstream end portion of the first stator, and

a plurality of blades peripherally affixed to the tubular body for disturbing drilling fluid flowing through the tubular housing, whereby particles in the drilling fluid are diverted from the one entrance.

[c8] 8.The apparatus of claim 2, wherein the bearings include radial bearings and axial bearings.

[c9] 9.The apparatus of claim 2, wherein the first rotor and first stator both have downstream end portions, the downstream end portion of the first stator extending downstream of the downstream end portion of the first rotor, the downstream end portions being sized and shaped so as to define an annulus therebetween adjacent the one exit into which drilling fluid flowing through the one exit will be accelerated to exert a lifting force on the first rotor relative to the first stator.

[c10] 10.The apparatus of claim 8, wherein the bearings include at least one axial bearing that employs a segmented ring for generating a hydrodynamic film of

drilling fluid that reduces the frictional contact at the one axial bearing.

[c11] 11.The apparatus of claim 9, wherein the bearings include at least one downstream axial bearing disposed between the downstream end portions, and further comprising an elastically-deformable member disposed between the downstream end portion of the first stator and the downstream axial bearing, whereby the flowing of drilling fluid through the tubular housing imposes a downward force on the impeller that moves the first rotor axially some distance downstream, compressing the member, and the member expands to lift the first rotor by the same distance when the drilling fluid flow is stopped.

[c12] 12.The apparatus of claim 11, wherein the elastically-deformable member has a spring constant that permits the first rotor to move axially downstream upon the startup of drilling fluid flow a distance sufficient to break a thixotropic gel that may have formed while the drilling fluid was static.

[c13] 13.The apparatus of claim 11, wherein the impeller defines a turbine rotor, and further comprising a turbine stator having
a tubular body attached coaxially to an upstream end

portion of the first stator, and

a plurality of blades peripherally affixed to the tubular body at a separation distance from the turbine rotor for disturbing drilling fluid flowing through the tubular housing so as to enhance the effect of the flowing drilling fluid upon the turbine rotor, and further wherein the elastically-deformable member has a spring constant that permits the first rotor and turbine rotor to move axially downstream during drilling fluid flow and increase the separation distance between the turbine rotor and the turbine stator to an extent that the effect of the flowing drilling fluid upon the turbine rotor is reduced, whereby the rotational velocity of the first rotor is restricted.

[c14] 14.The apparatus of claim 13, further comprising a divergent conical member adapted for attachment within the tubular housing and being sized and shaped so as to permit axial movement of the first rotor and turbine rotor therein, whereby axial downstream movement of the first rotor and turbine rotor within the divergent conical member positions the turbine rotor in a region of reduced-velocity drilling fluid flow which reduces the rotational velocity of the first rotor.

[c15] 15.The apparatus of claim 11, wherein the axial movement downstream by the first turbine during drilling

fluid flow reduces the coverage by the array of magnets within the first rotor about the array of conductive windings within the first stator, whereby the generation of electrical power is reduced.

[c16] 16.The apparatus of claim 1, wherein the array of conductive windings within the first stator are arranged therein so as to facilitate the monitoring of each winding"s voltage output, whereby eccentricity of the first rotor relative to the first stator can be determined.

[c17] 17.The apparatus of claim 1, wherein the array of conductive windings within the first stator are arranged by the internal structure of the stator such that the windings are asymmetrically distributed about the first stator, and the array of magnets within the first rotor are arranged therein about an inner rim of the first rotor, whereby the first rotor applies a resultant magnetic attraction force on the first stator in a fixed radial direction that inhibits whirling by the first rotor.

[c18] 18.The apparatus of claim 16, further comprising an electronic controller for separately adjusting the current flowing through each winding so as to counteract the eccentricity, whereby whirling of the first rotor is inhibited.

[c19] 19.The apparatus of claim 1, wherein

the first rotor has a non-uniform circumference defined by a first diameter and a second diameter, the second diameter being greater than the first diameter,
the impeller is peripherally affixed to a portion of the first rotor having a circumference defined by the first diameter, and
the array of magnets within the first rotor are carried in a portion of the first rotor having a circumference defined by the second diameter.

[c20] 20.A system for generating electrical power in a drill string disposed in a borehole, comprising:
a tubular housing connected within the drill string;
a stator secured within the tubular housing against rotation relative to the tubular housing, the stator having an array of conductive windings therein;
a tubular rotor rotatably carried about the stator, the rotor having an array of magnets therein; and
an impeller peripherally affixed to the rotor;
whereby drilling fluid flowing through the drill string engages the impeller and induces rotation of the rotor about the stator to generate electrical power.

[c21] 21.The system of claim 20, wherein the tubular housing is a drill collar.

[c22] 22.The system of claim 21, further comprising a MWD

sensor package and a telemetry device, both disposed in the drill collar and powered by the generated electrical power.

[c23] 23.A method for generating electrical power in a borehole, the method comprising the steps of:
rotatably supporting a rotor about a stator, the rotor having a peripheral impeller;
securing the stator within a drill string against rotation relative to the drill string, the drill string being disposed in the borehole; and
flowing drilling fluid through the drill string, whereby the impeller converts the hydraulic energy of the drilling fluid into rotation of the rotor about the stator to generate electrical power.

[c24] 24.The method of claim 23, wherein the rotor is rotatably supported about the stator by bearings that are lubricated by the drilling fluid flowing through the drill string.

[c25] 25.The method of claim 23, further comprising the step of conducting the flowing drilling fluid through a gap between the stator and the rotor to remove heat from the stator.

[c26] 26.The method of claim 25, further comprising the step

of preventing a buildup of drilling fluid particles within the gap.

[c27] 27.The method of claim 23, further comprising the step of diverting particles in the drilling fluid from being conducted between the rotor and stator.

[c28] 28.The method of claim 24, wherein the bearings include at least one axial bearing, and further comprising the step of reducing the frictional contact at the one axial bearing.

[c29] 29.The method of claim 23, further comprising the step of breaking a thixotropic gel that formed between the rotor and stator while the drilling fluid was static.

[c30] 30.The method of claim 23, further comprising the step of controlling the rotational velocity of the rotor.

[c31] 31.The method of claim 23, further comprising the step of controlling the generation of electrical power.

[c32] 32.The method of claim 24, further comprising the step of predicting the wear of the bearings.

[c33] 33.The method of claim 23, further comprising the step of inhibiting whirling by the rotor.